Ground Deformation Monitoring at Natural Gas Production Sites using Interferometric SAR

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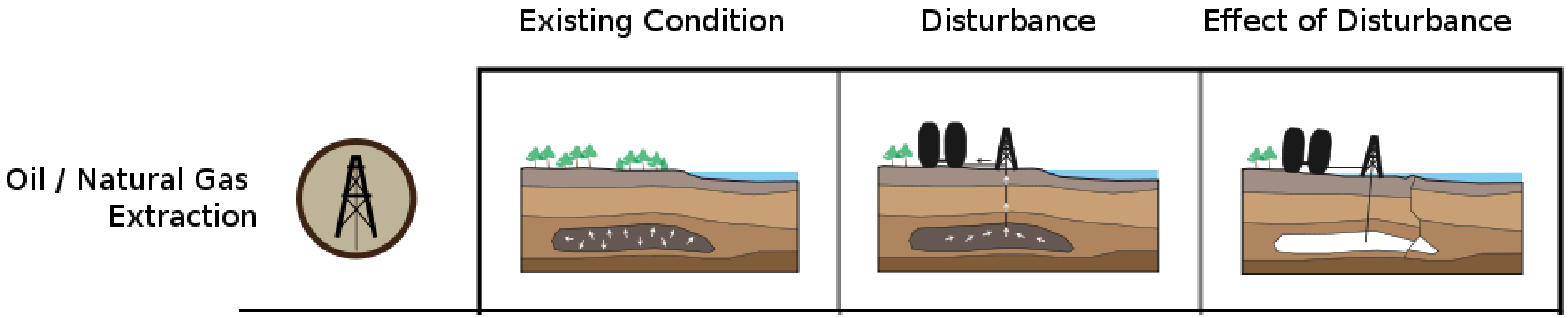
DLR

Introduction

Motivation

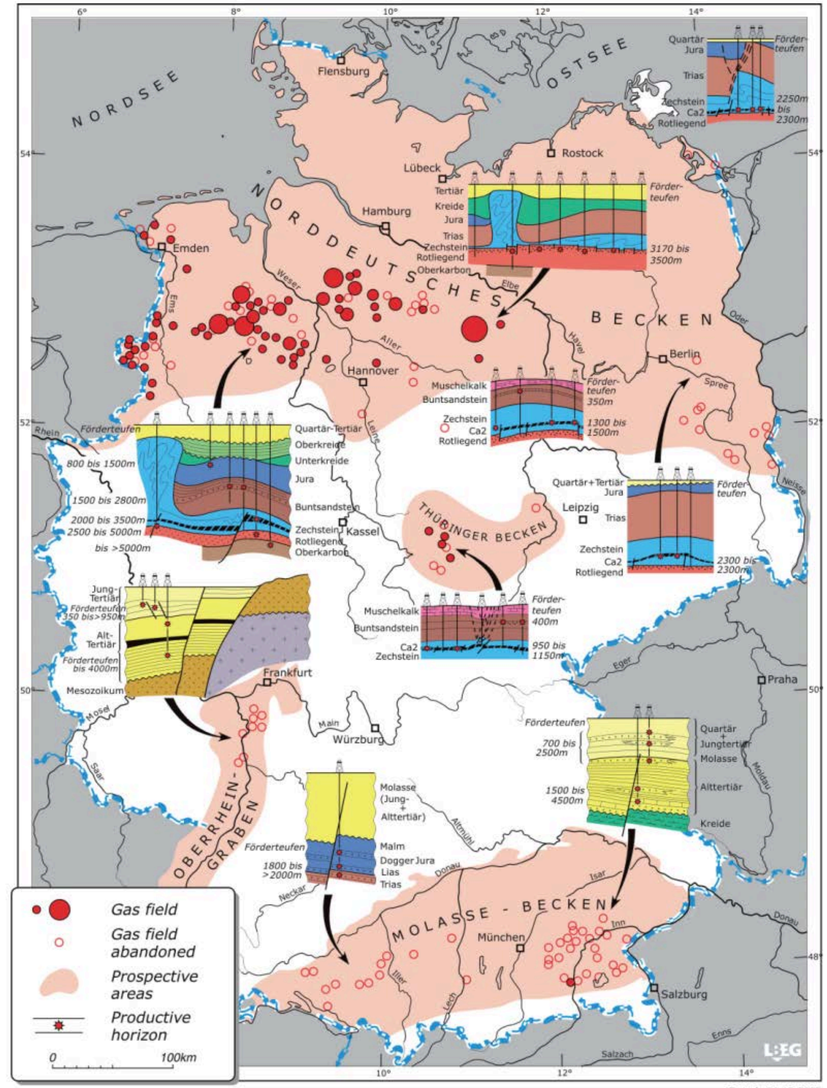
- Natural gas production has increased significantly to meet energy demands
- Extraction leads to decreased reservoir pressure and may cause subsidence
- Monitoring this subsidence important for geological and hazard analysis



Ground deformation illustration

Natural Gas in Germany

- Small volumes produced as compared internationally
- In 2007, 17% domestic consumption from domenstic production
- Lower-Saxony accounted for 93% of German natural gas production
- BGR, Germany, collaborating with DLR for monitoring subsidence due to natural gas extraction



Source: BGR, Germany

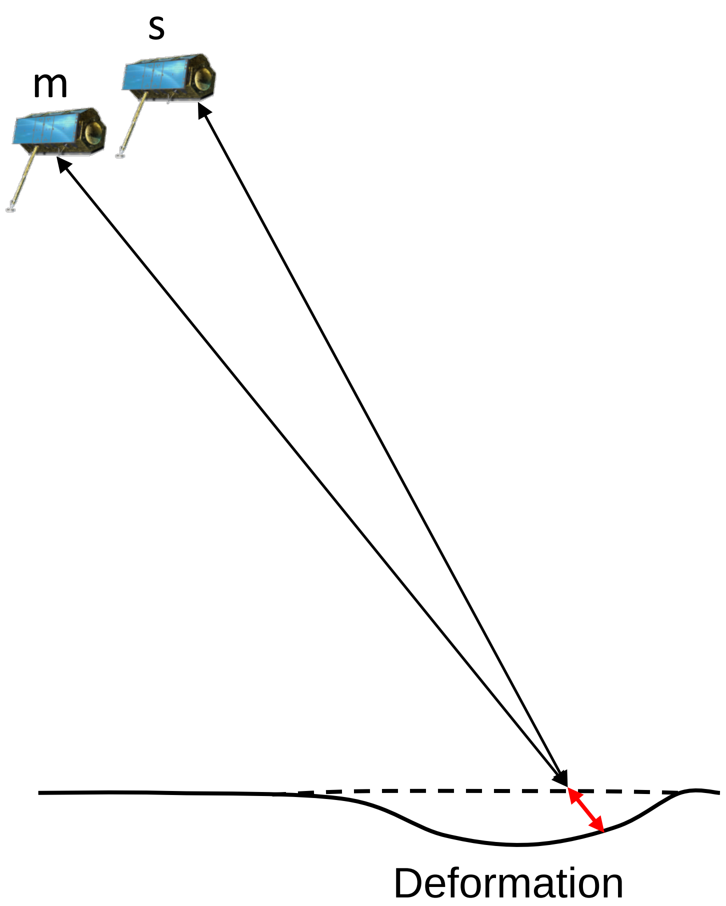
Interferometric SAR (InSAR)

- Powerful remote sensing technique for detecting ground deformation

- Deformation estimation using 2 SAR images and Digital Elevation Model (DEM)

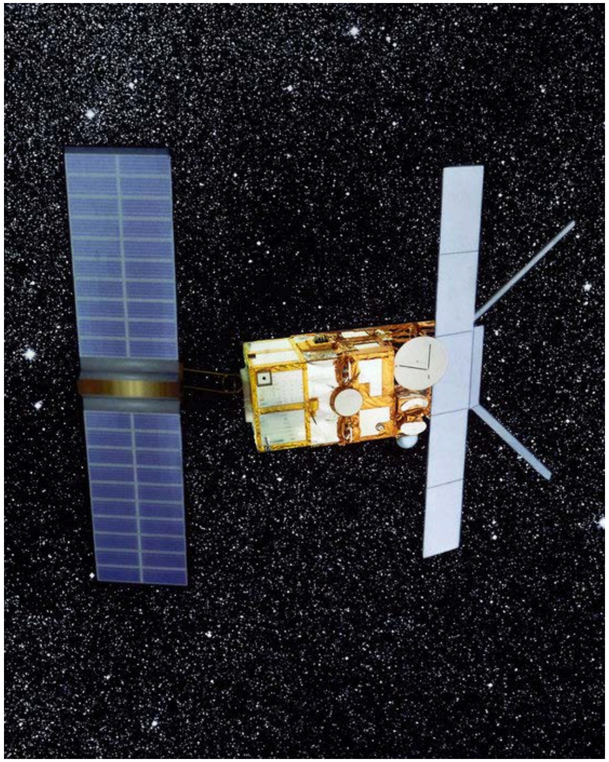
- Interferogram phase contributions:

$$\boxed{\varphi_{InSAR} = \varphi_{defo} + \varphi_{topo} + \varphi_{atmo} + \varphi_{noise}}$$



C-Band SAR

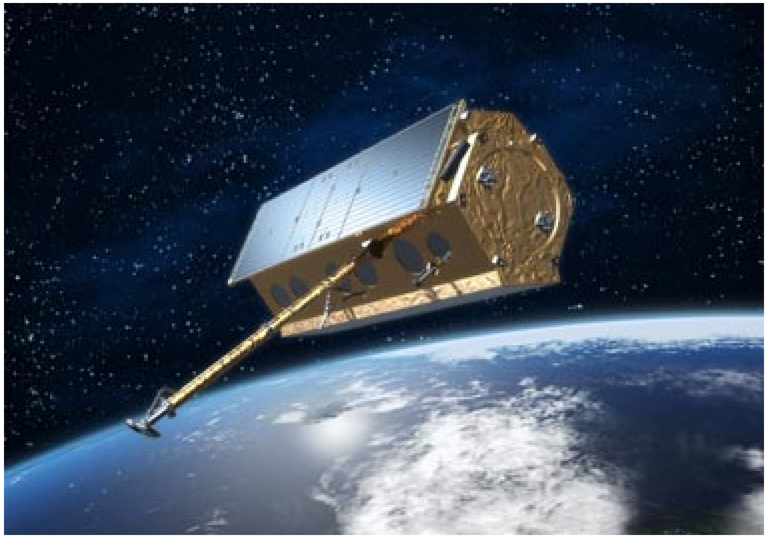
- Medium resolution of 25 m
- 5.6 cm wavelength
- 100 km swath width



ERS

X-Band SAR

- High resolution of up to 1 m
- 3.1 cm wavelength
- High sensitivity to even millimetric displacements

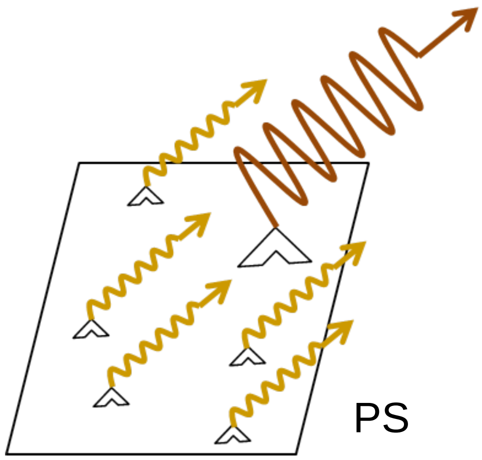


TerraSAR-X (TSX)

Methodology

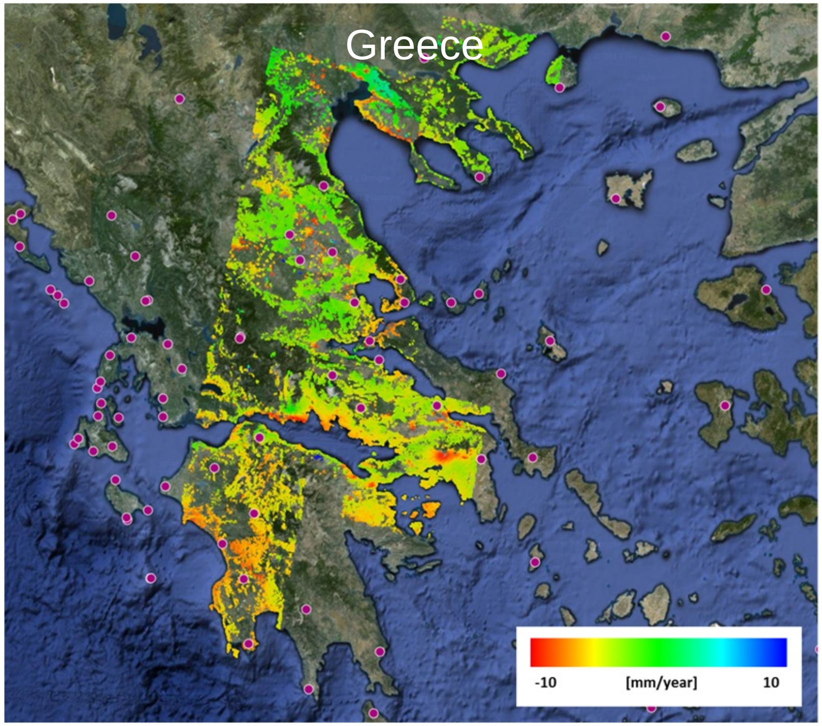
Persistent Scatterer Interferometry (PSI)

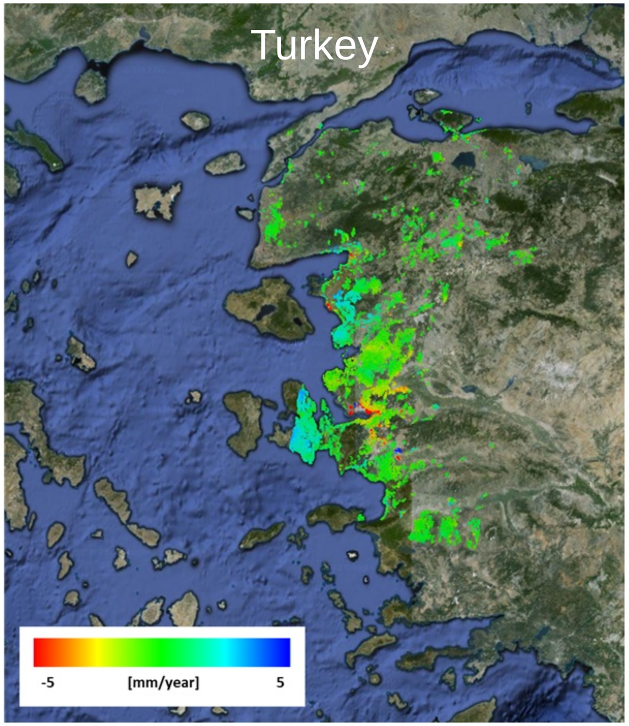
- Coherent InSAR stacking technique
- Permanently coherent PSs exploited
- Differential interferograms wrt a single master image used
- Model-based deformation estimation



DLR‘s Integrated Wide Area Processor (IWAP)

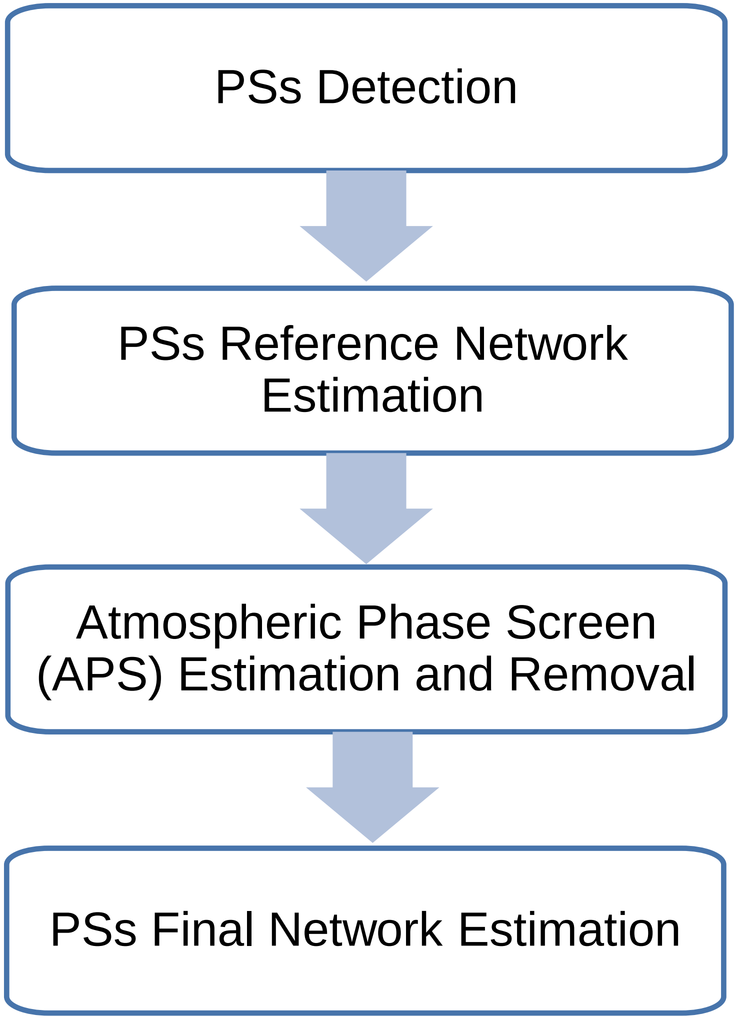
- Highly automated, efficient and robust multi-sensor PSI-GENESIS software
- Successful demonstration and validation during ESA's Terrafirma project





Source: Rodriguez Gonzalez et al., 2013

PSI Algorithm



PSI Algorithm

PSs Detection

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PSs Reference Network Estimation

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Atmospheric Phase Screen (APS) Estimation and Removal

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PSs Final Network Estimation

PSs Reference Network Estimation- Block Processing

- Division of scene into overlapping blocks
- Blockwise creation of reference network (arcs connecting the PSs)
- Blockwise estimation of relative deformation and residual DEM for the arcs using LAMBDA estimator
- Blockwise network inversion to estimate deformation and residual DEM for the PSs using least squares
- Merging of independently estimated blocks via least squares adjustment

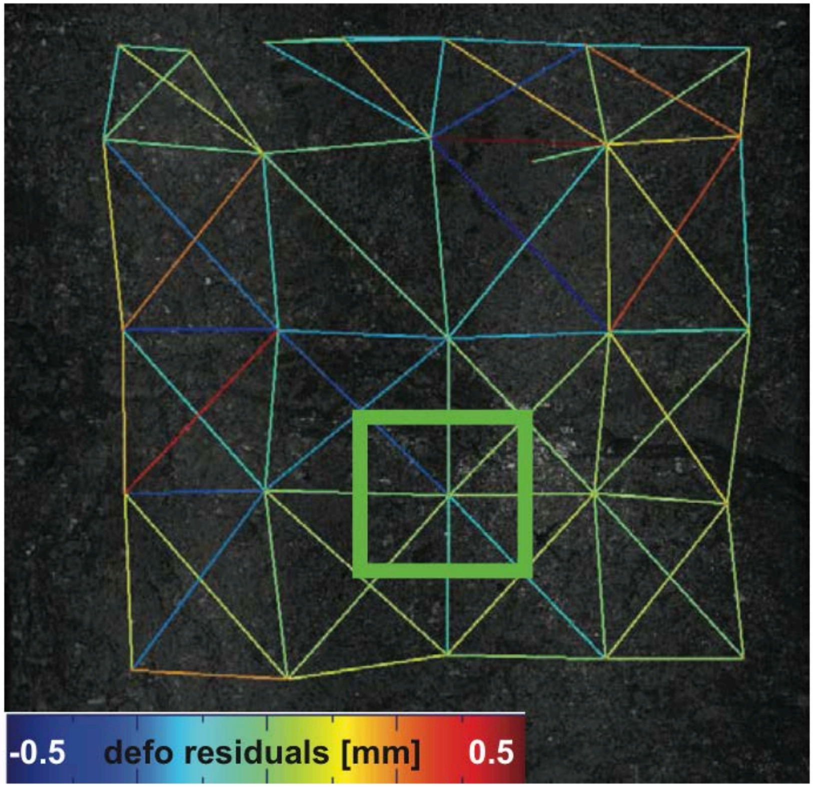


Illustration of block adjustment network

Developed by: Werner Liebhart

PSs Reference Network Estimation- Single Network

- Creation of reference network (arcs connecting the PSs)
- Estimation of relative deformation and residual DEM for the arcs using LAMBDA estimator
- Single network inversion to estimate deformation and residual DEM for the PSs using least squares

Mitigates error propagation

High computational load and memory consumption

PSs Reference Network Estimation- Single Network

Sinlge network inversion- Strategies:

- Solve $A x = B \Rightarrow A^T A x = A^T B$
- $A^T A$ is symmetric positive definite square matrix
- Exploit sparsity of $A \Rightarrow A^T A$
- Use QR or LU decomposition for fast inversion, instead of SVD decomposition
- Use a parallelizable solver
- Estimate deformation, residual DEM and standard deviation of estimates

PSs Reference Network Estimation- Single Network

Example matrix A dimensions:

- TerraSAR-X Stripmap:

  Size(A) = (30000, 600000)

- ERS:

  Size(A) = (90000, 1800000)

- Sentinel-1:

  Size(A) = (450000, 9000000)

PSs Reference Network Estimation- Single Network

Example matrix A dimensions:

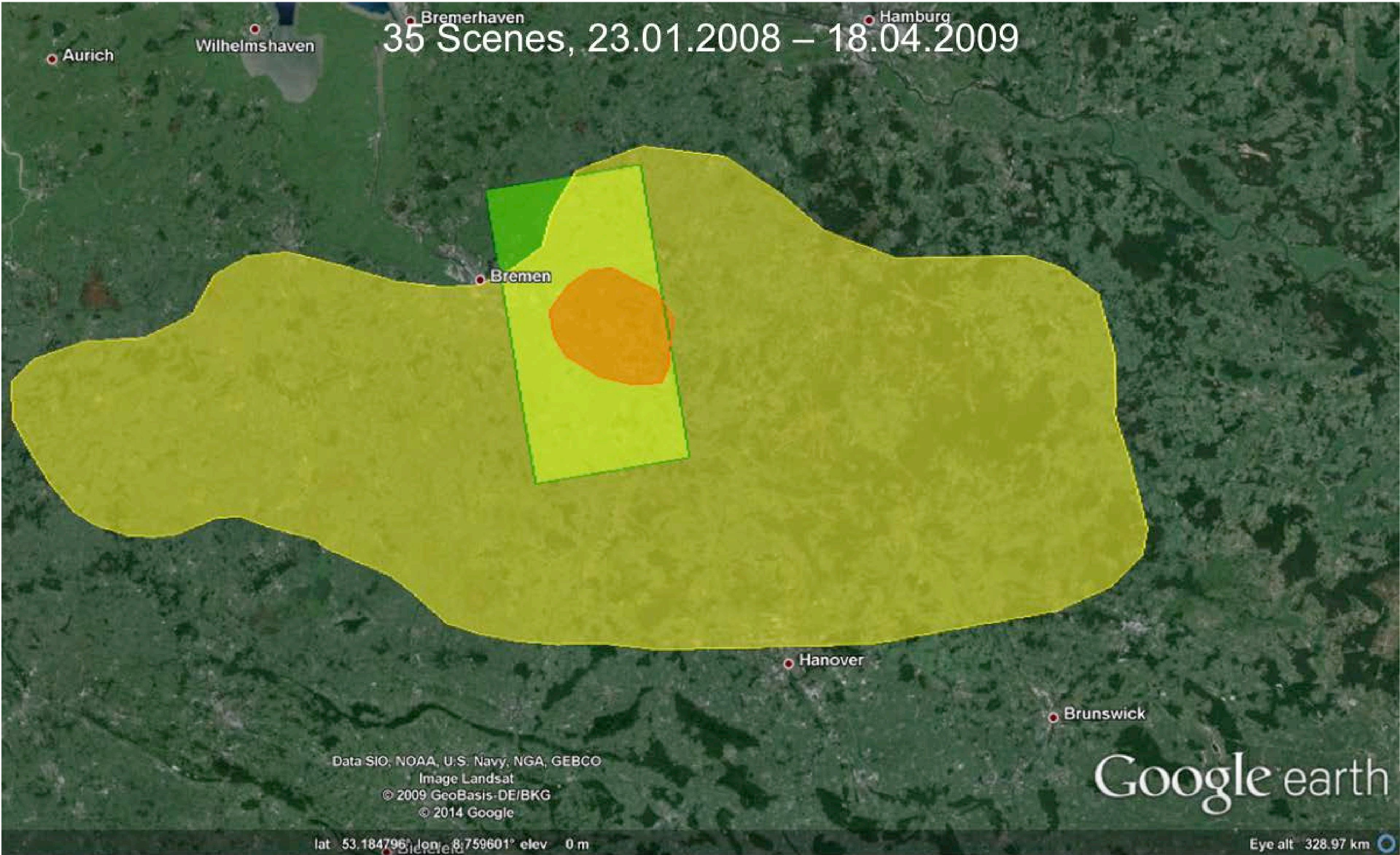
- TerraSAR-X Stripmap:
  Size(A) = (30000, 600000)
- ERS:
  Size(A) = (90000, 1800000)
- Sentinel-1:
  Size(A) = (450000, 9000000)

Example matrix A^TA dimensions:

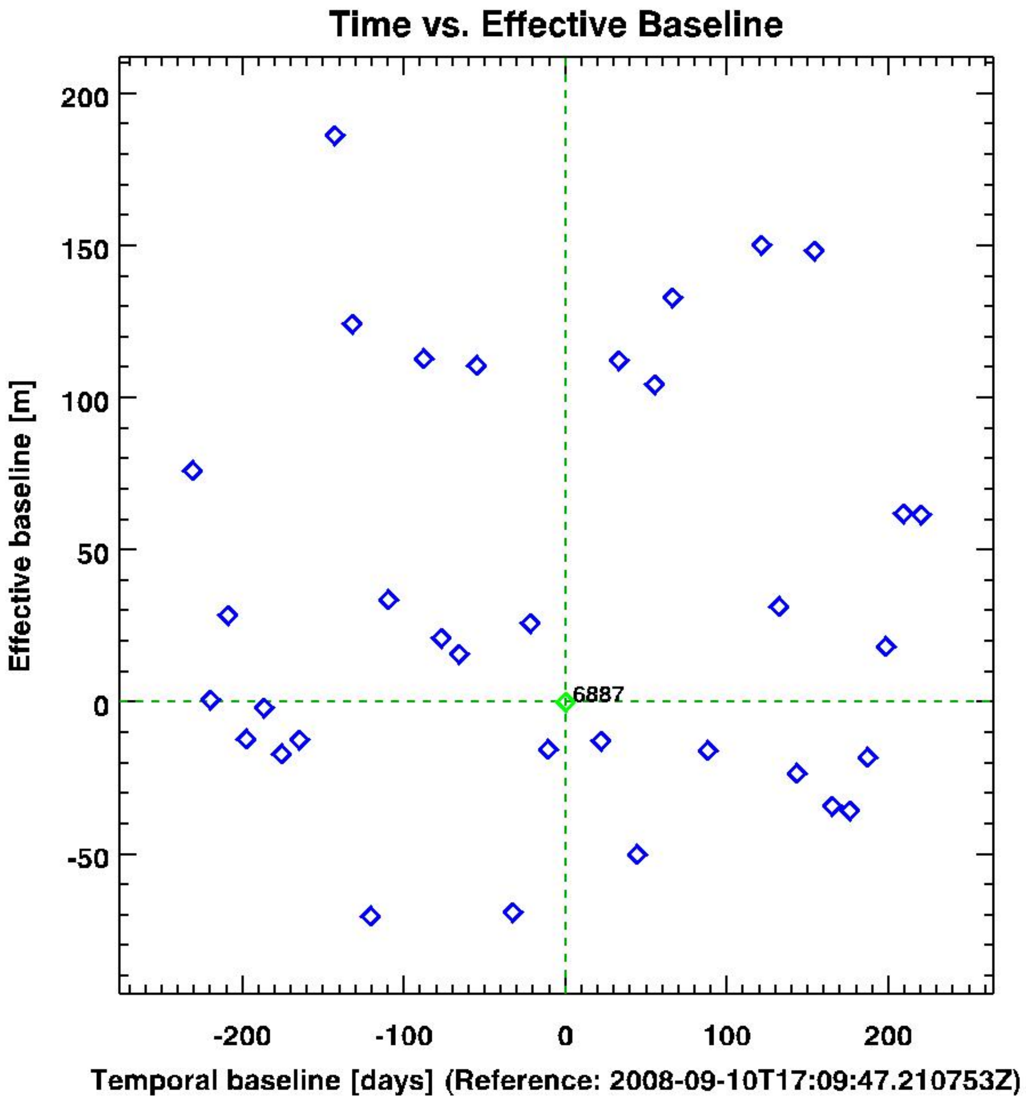
- TerraSAR-X Stripmap:
  Size(A^TA) = (30000, 30000)
- ERS:
  Size(A^TA) = (90000, 90000)
- Sentinel-1:
  Size(A^TA) = (450000, 450000)

Application Test Case and Results

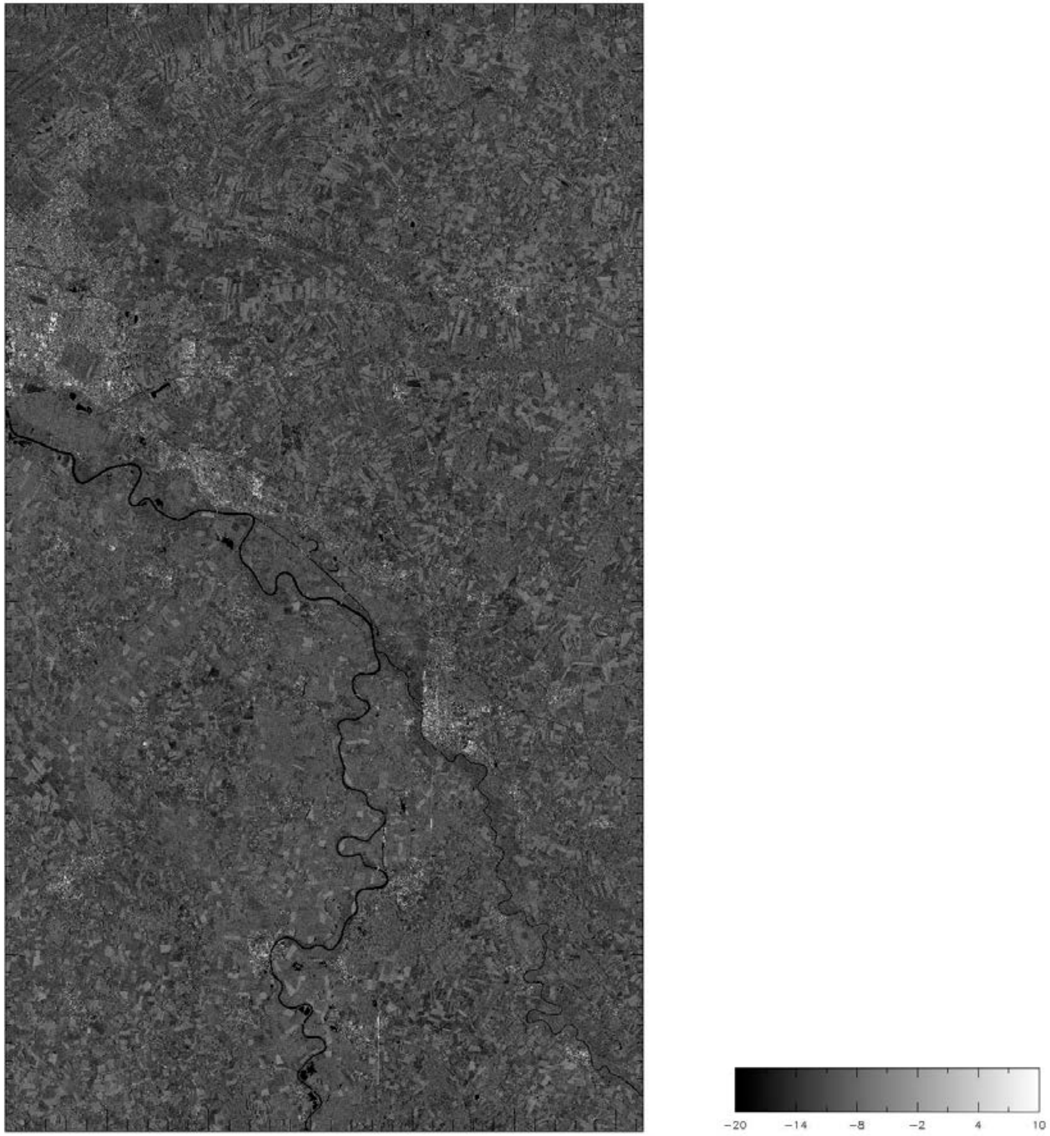
TSX Data- Ascending Stripmap Stack



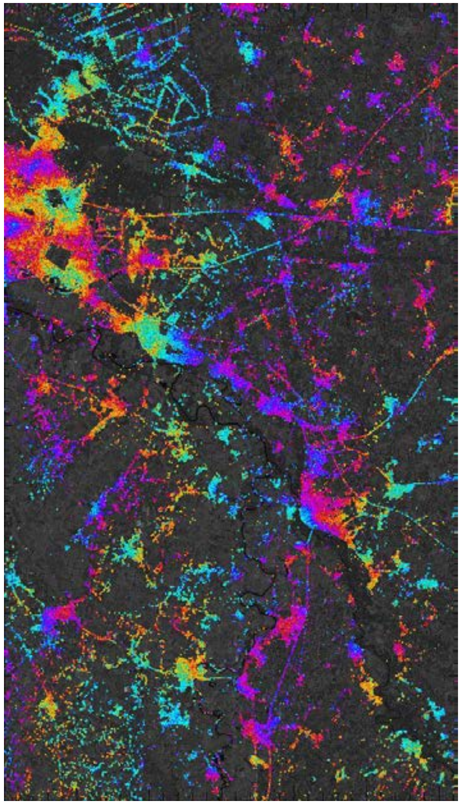
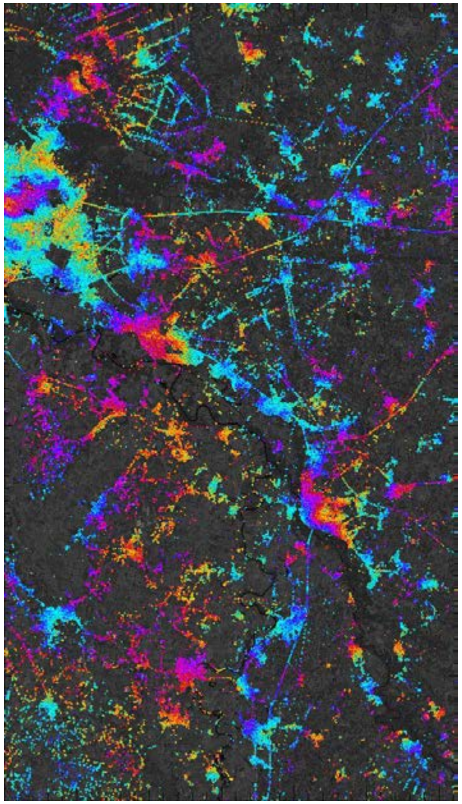
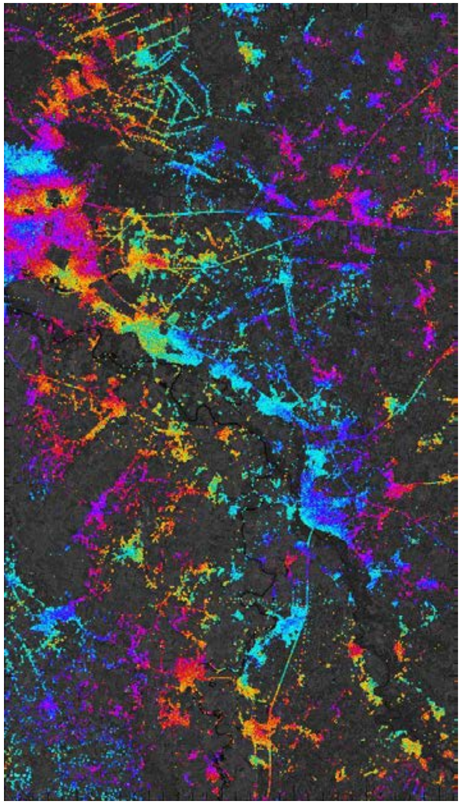
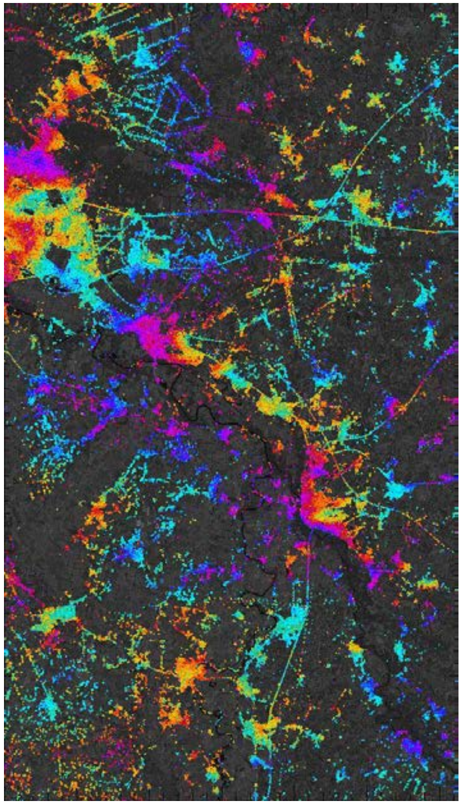
Time – Baseline Plot



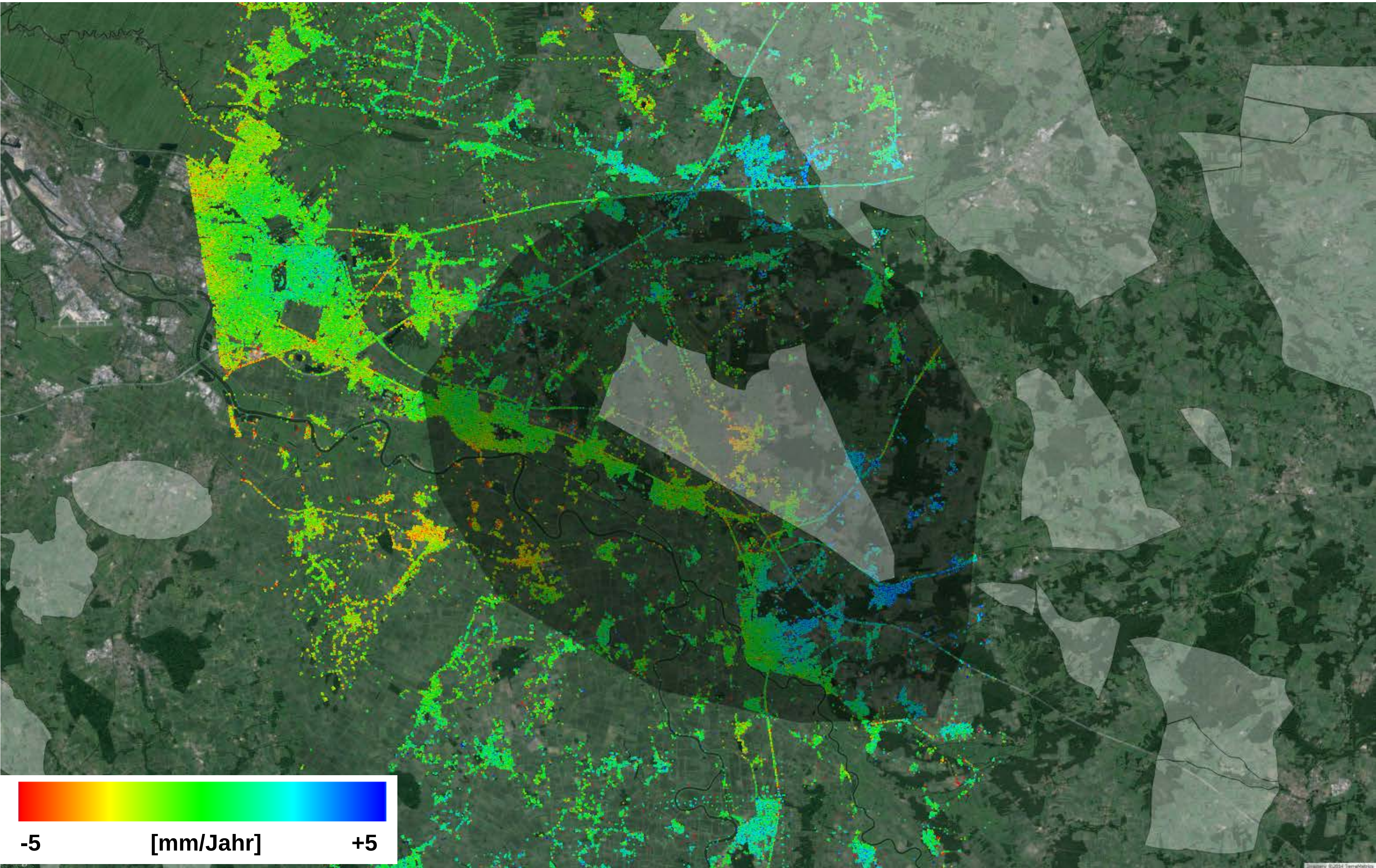
Master Amplitude Image



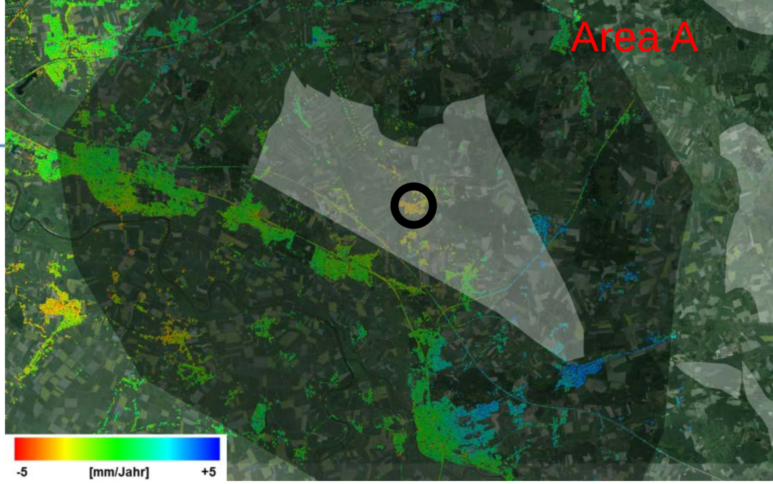
Interferogram Examples

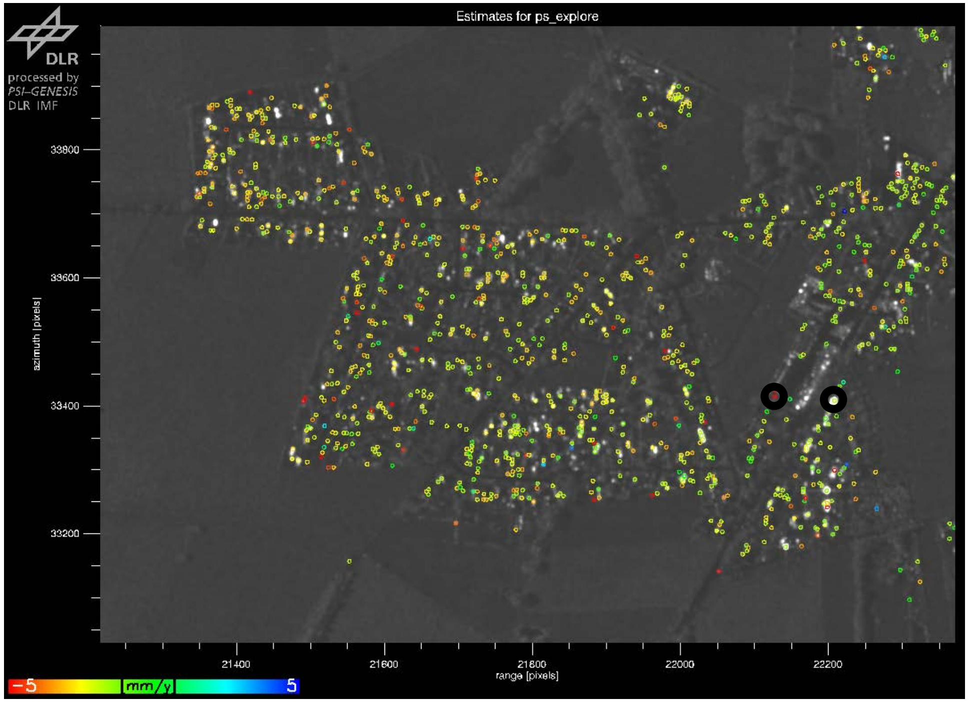





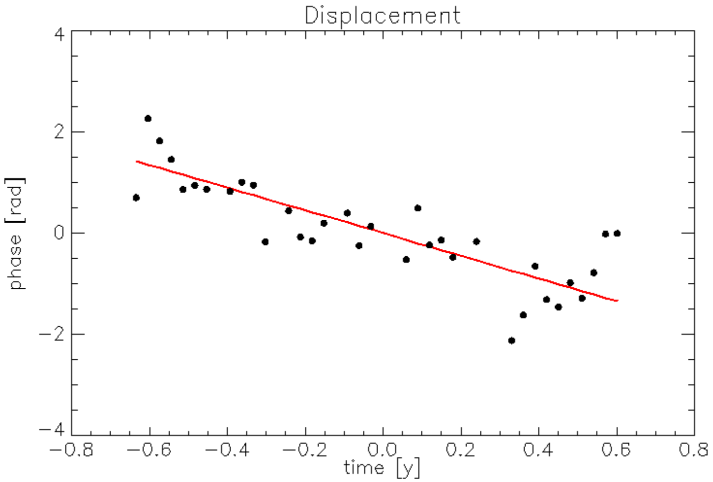
Deformation Estimation Results



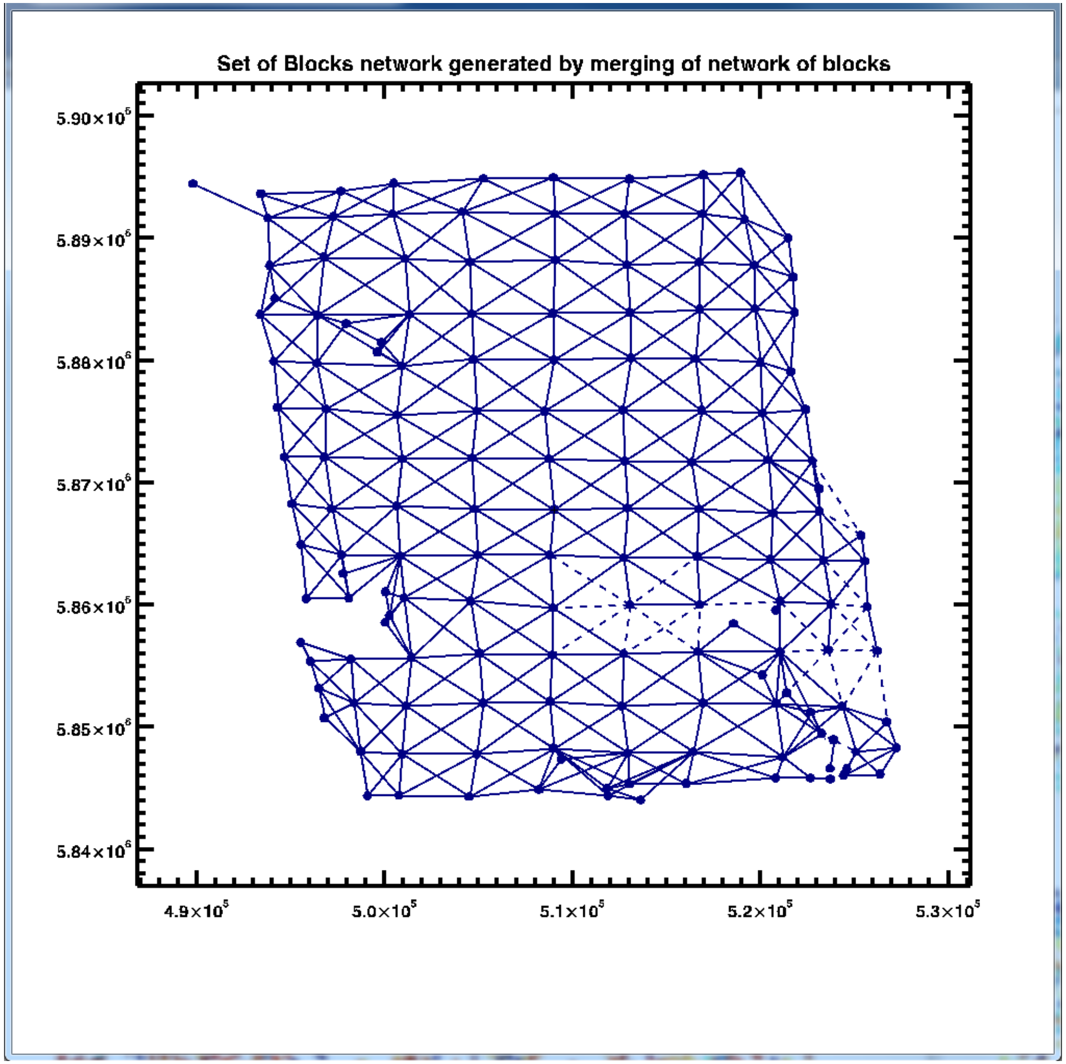
Deformation Time Series Example







PSs Reference Network Estimation- Block Processing



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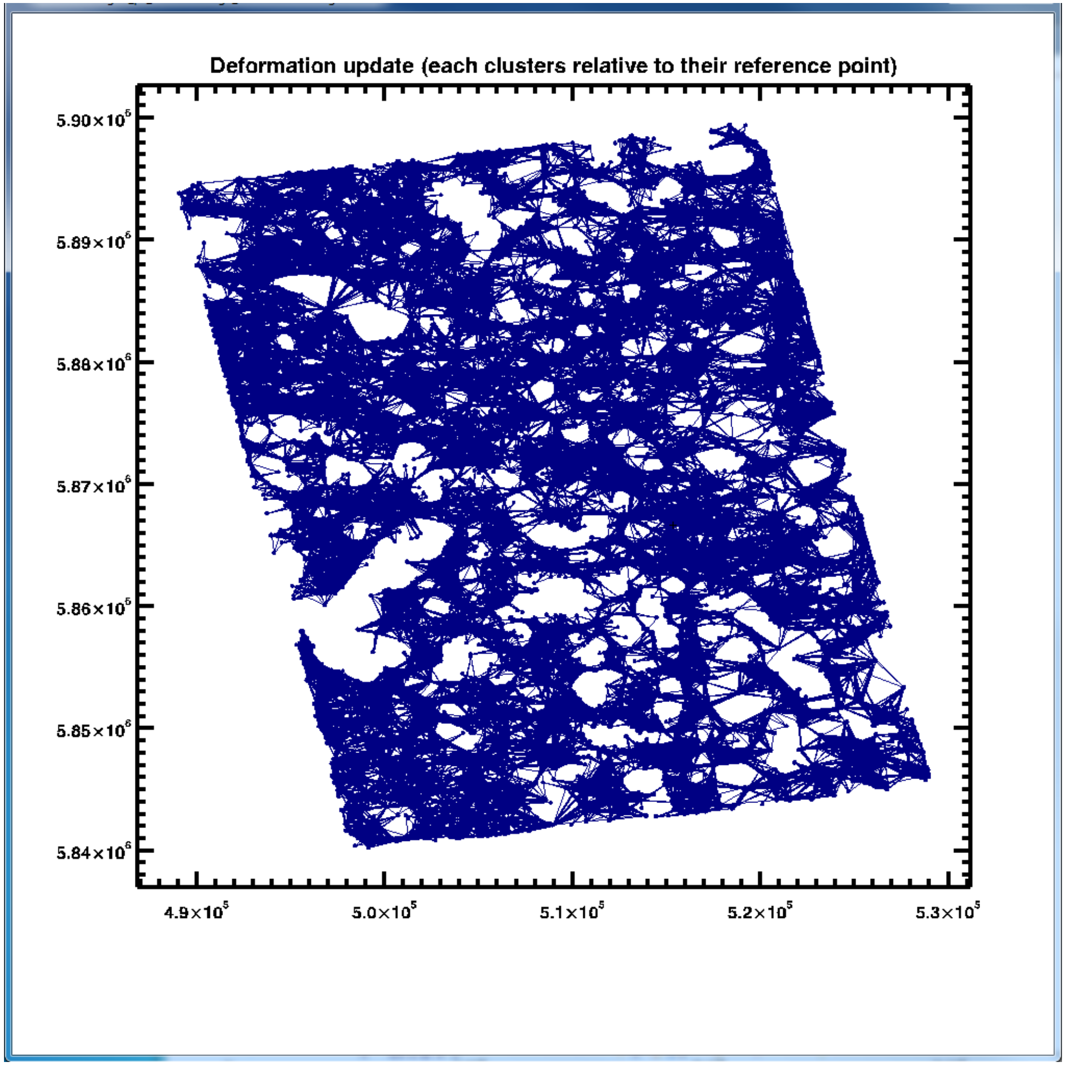
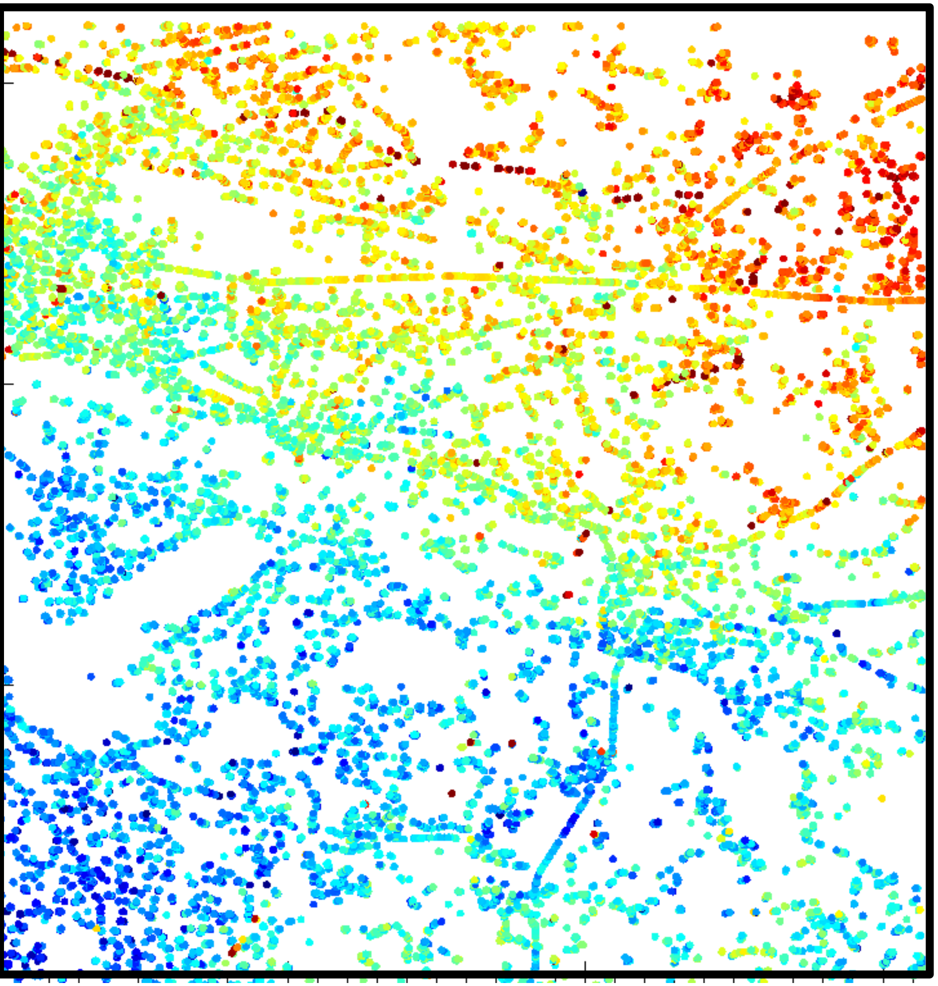
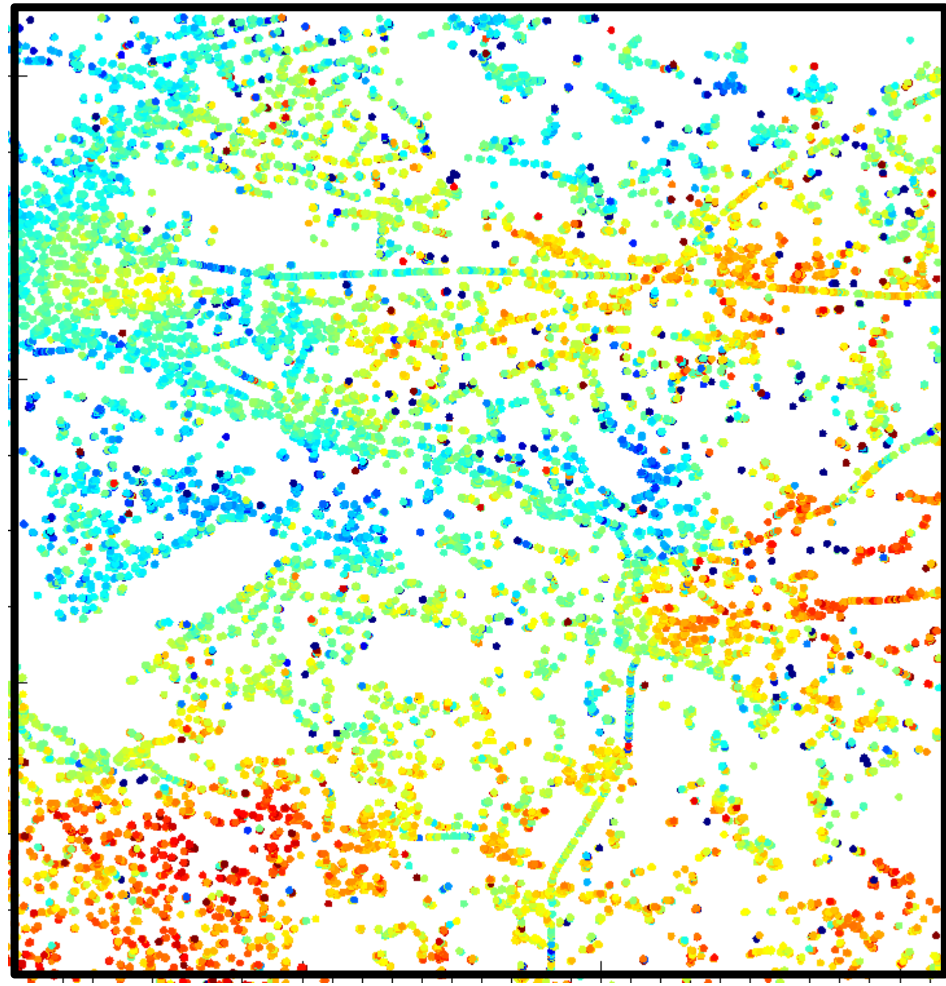


PSs Reference Network Estimation- Block Processing



Residual topography

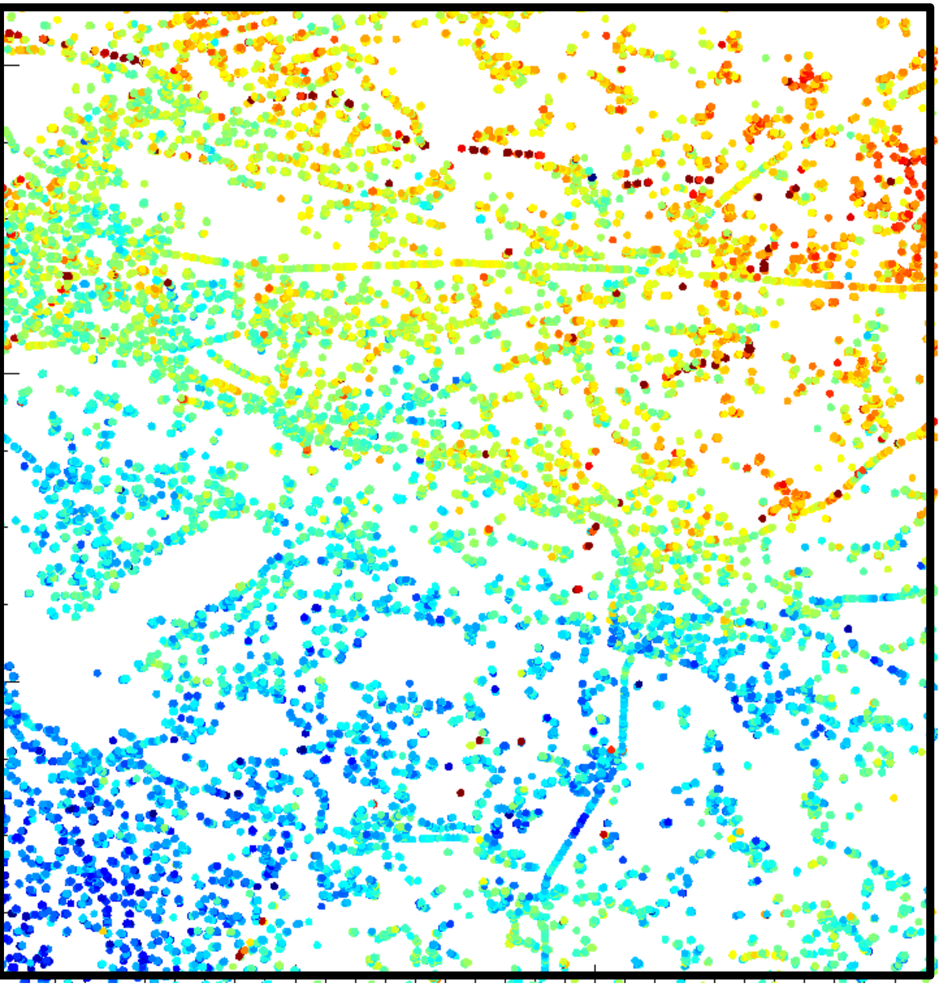
-20 mm +20



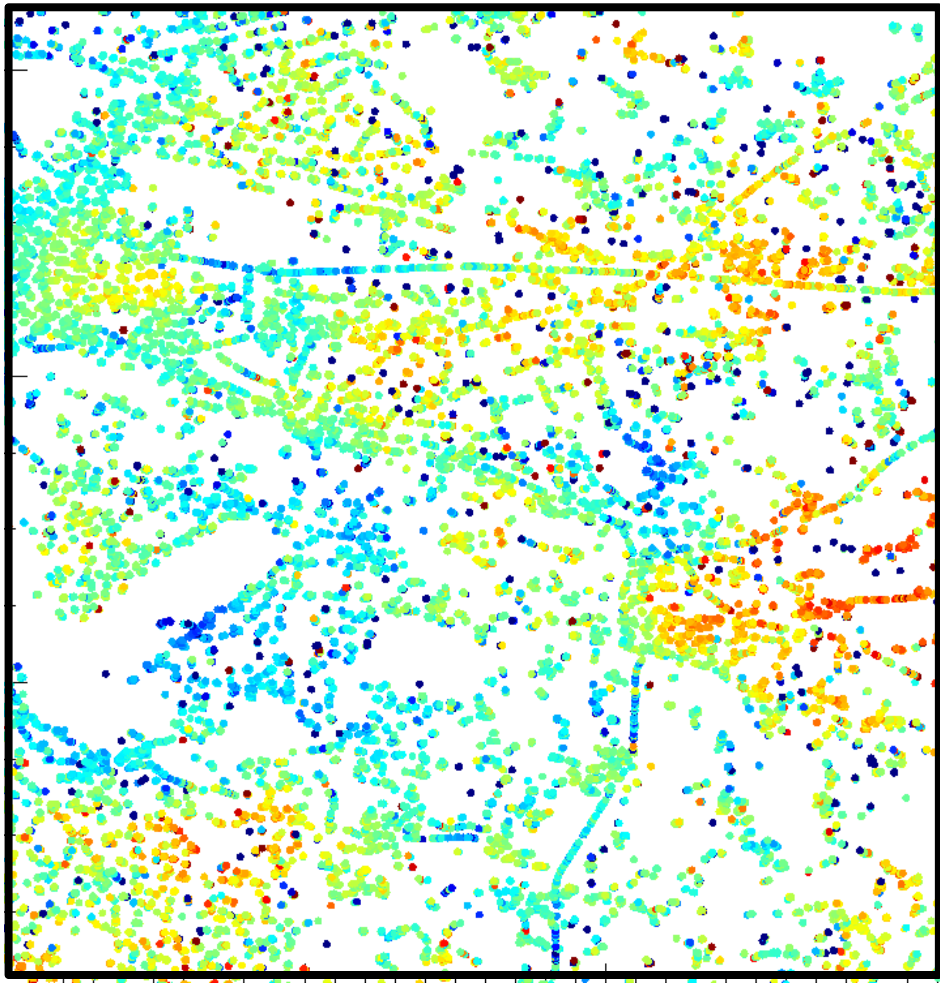
Deformation

-5 mm/yr +5

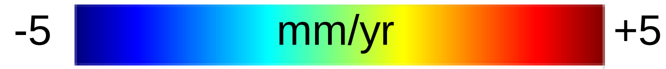
PSs Reference Network Estimation- Single Network



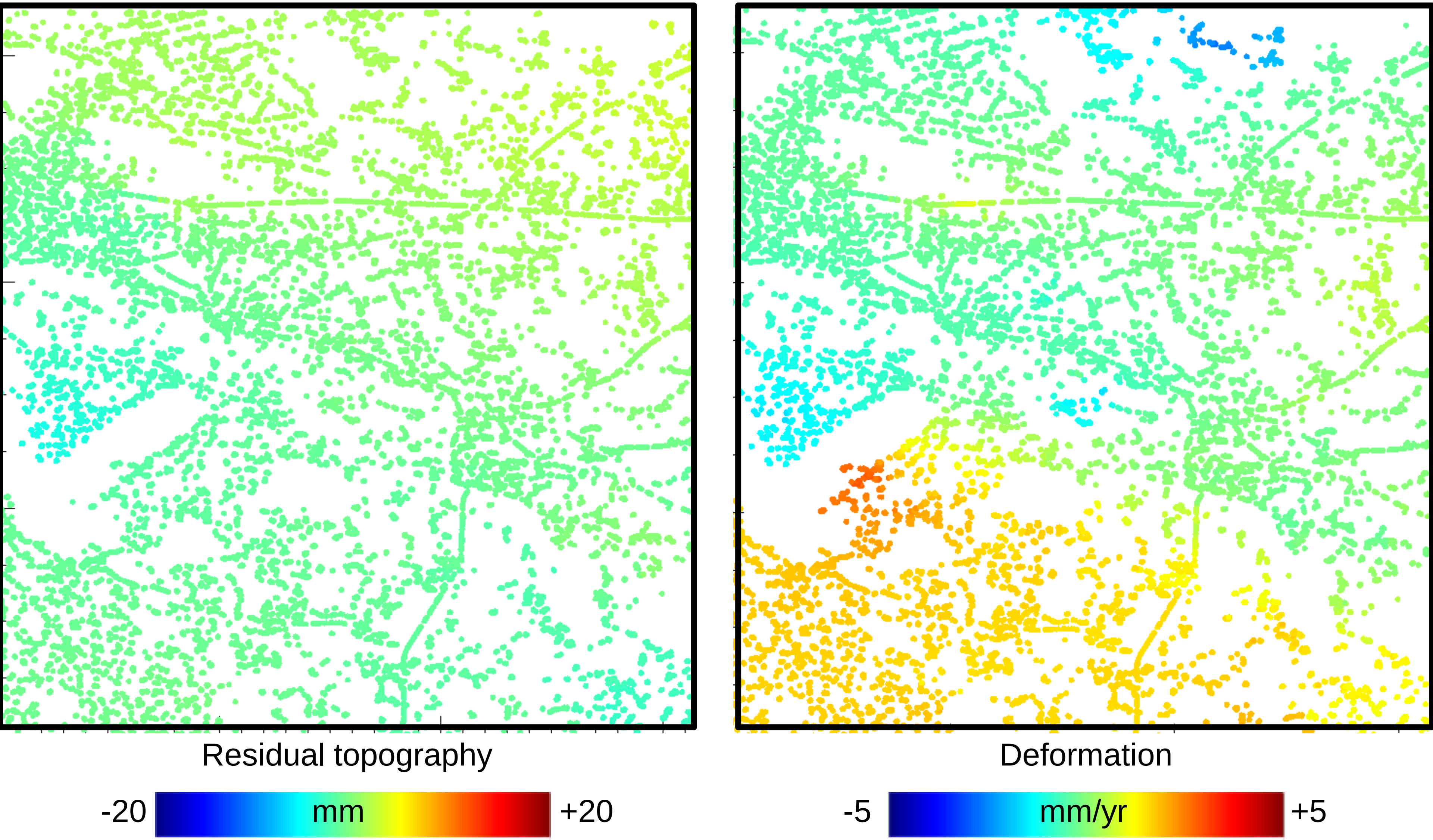
Residual topography



Deformation



PSs Reference Network Estimation- Difference



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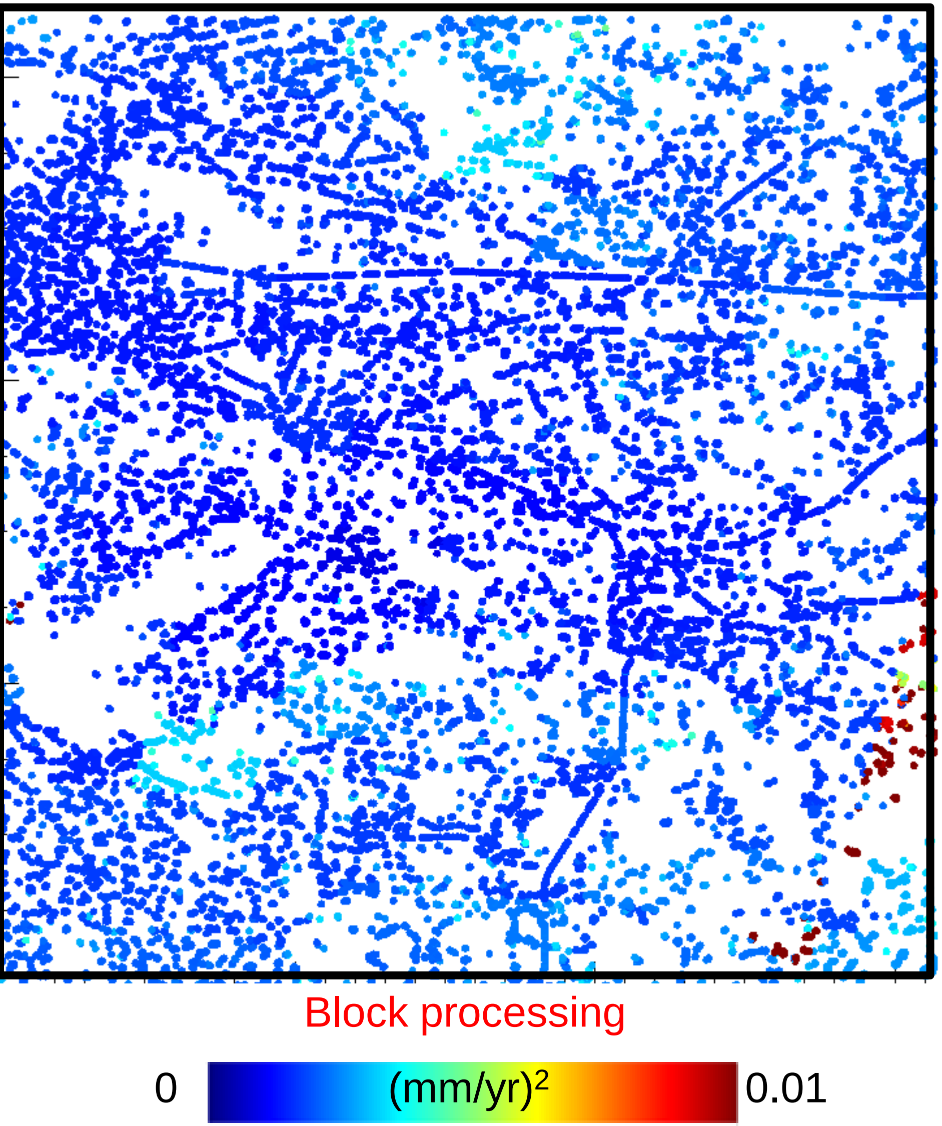
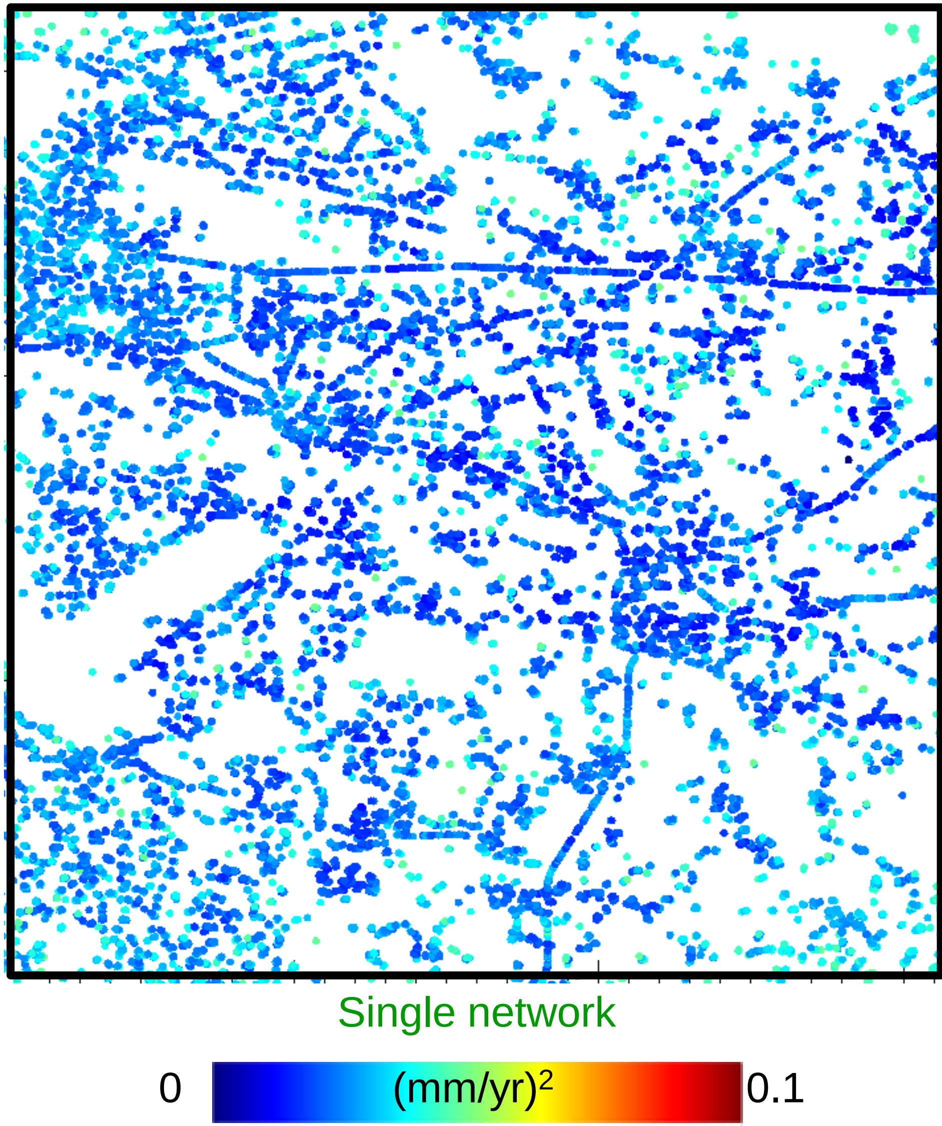
PSs Reference Network Estimation- Deformation Variance





Summary

Conclusion and Outlook

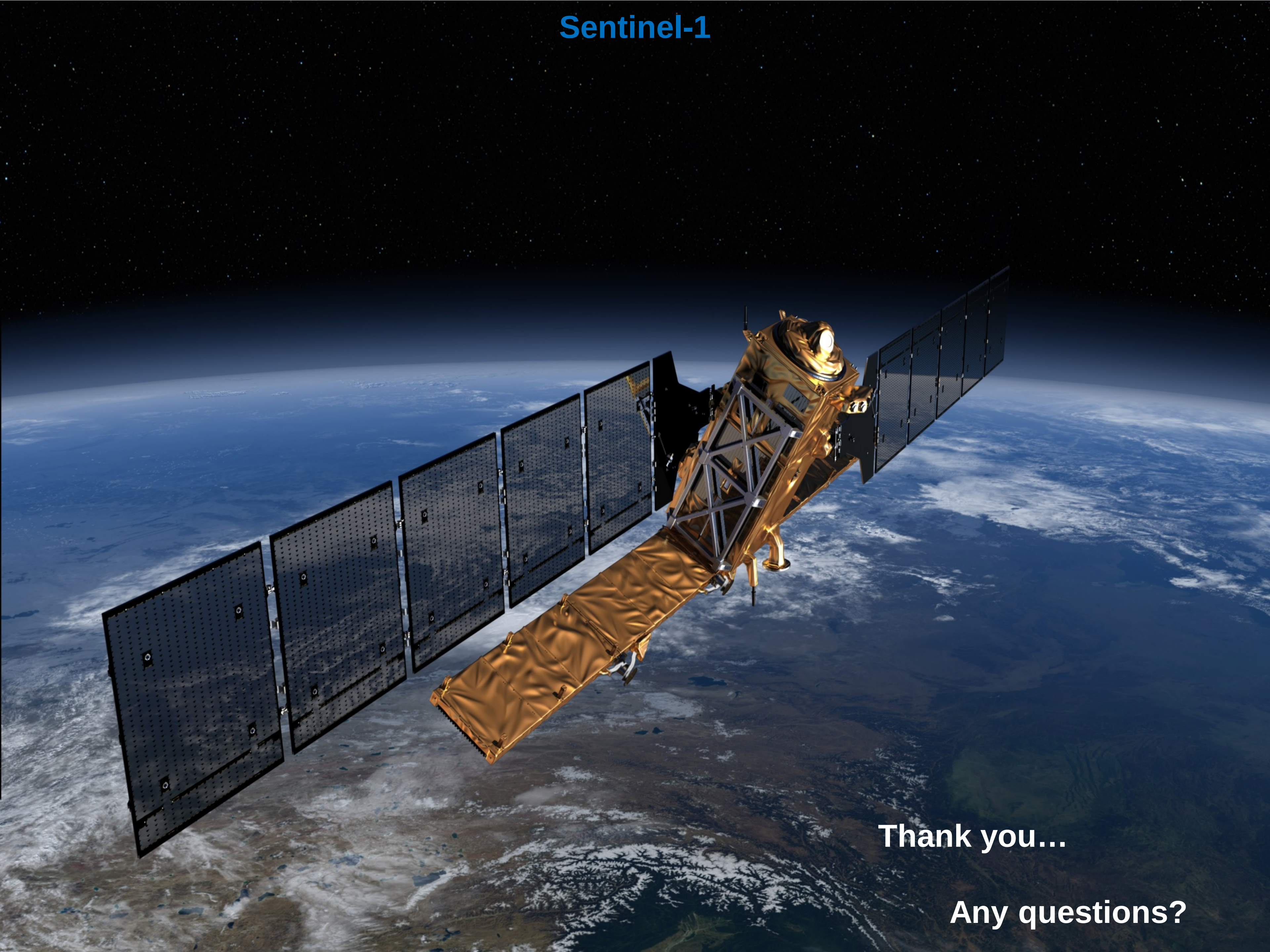
- PSI powerful and cost-effective tool for monitoring the impact of hydrocarbon reservoirs

- Single reference network inversion has potential to improve the deformation velocity maps

- Comparison with GPS data would be performed in the future to validate the pilot study

- Sentinel-1 data would be acquired for large area monitoring

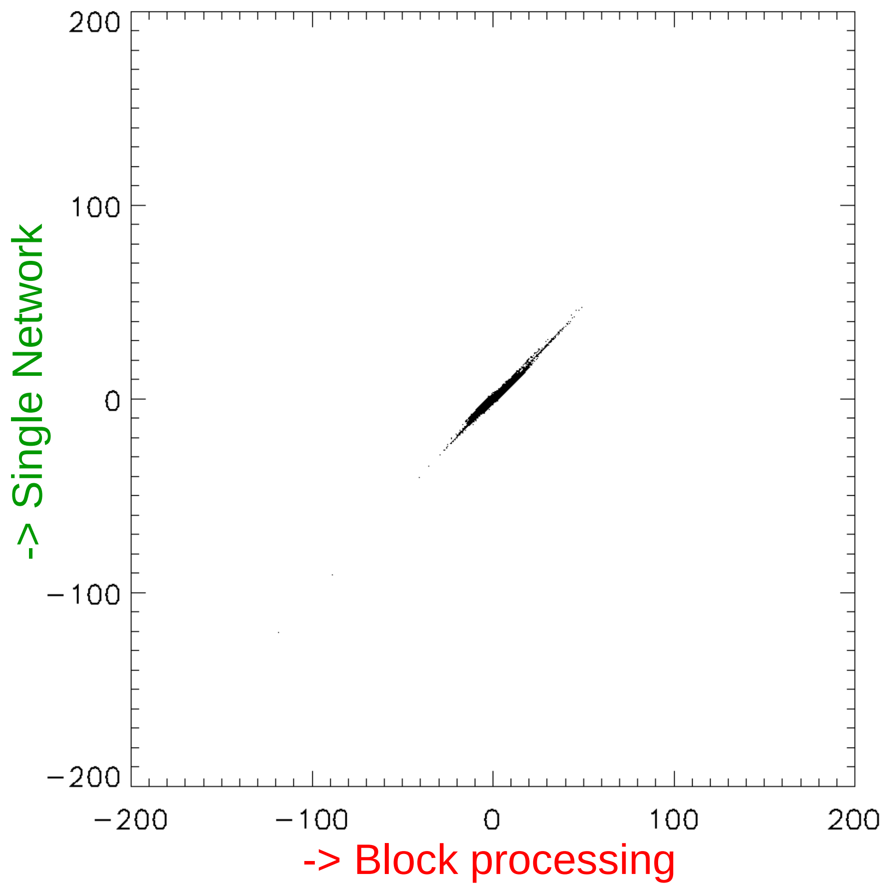
Sentinel-1



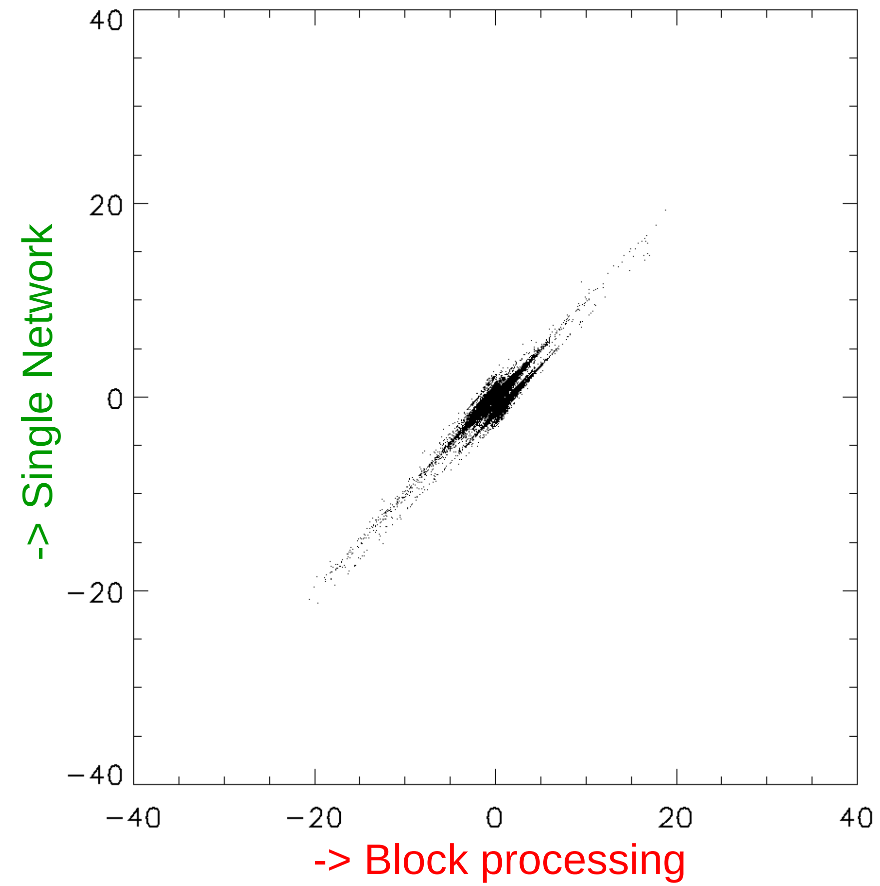
Thank you…

Any questions?

PSs Reference Network Estimation- Scatter Plot

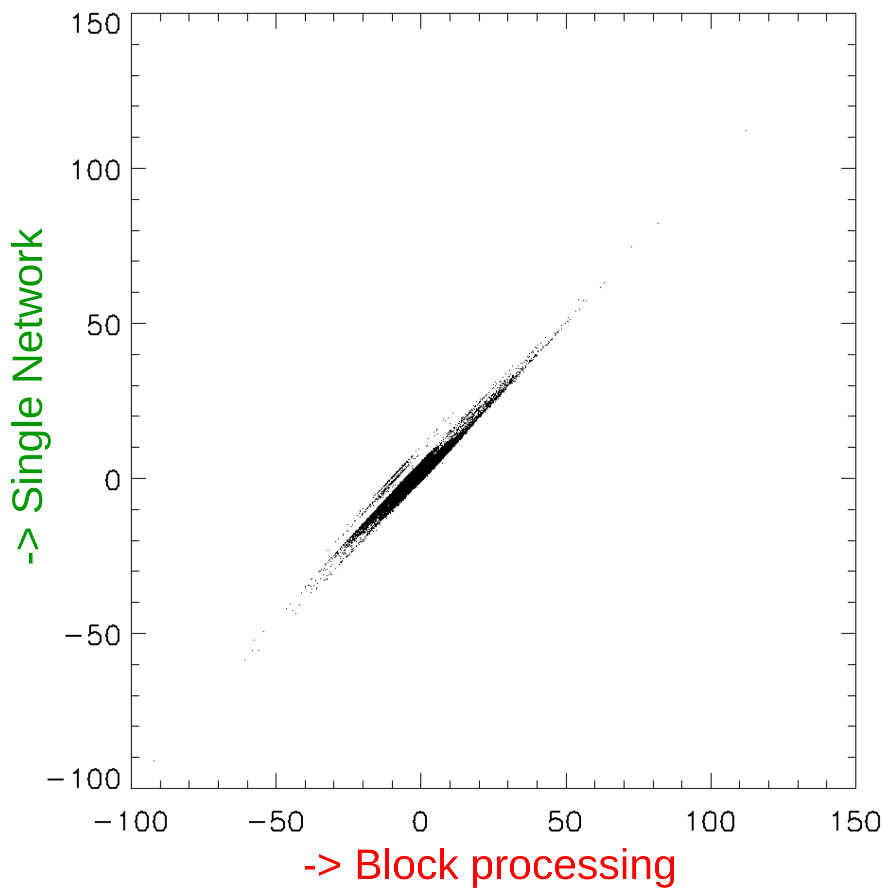


Residual topography

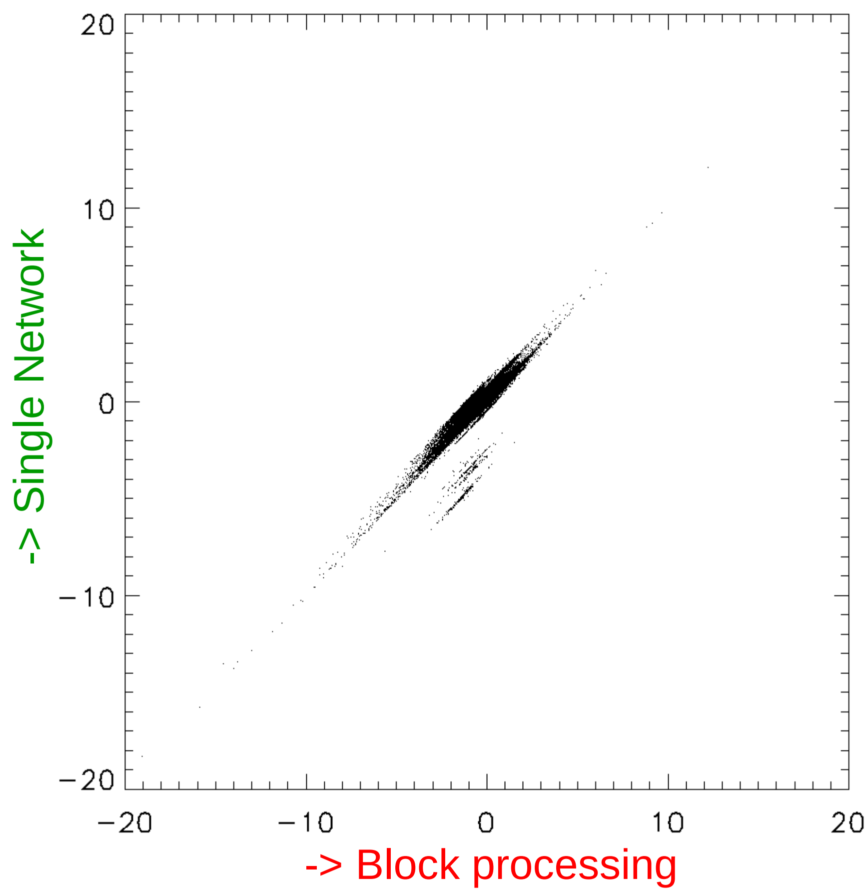


Deformation

PSs Reference Network Estimation- Scatter Plot



Residual topography



Deformation

DLR